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Global change effects on land management in the Mediterranean region

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ABSTRACT

The Mediterranean region faces significant challenges to supply its growing population with food and living space. The region's potential to do so in the future is even more uncertain in the light of global change effects. Climate change will impact water availability in the region, which is already limited and often used at unsustainable rates. To investigate the effects of global change and explore alternative development pathways of Mediterranean land use, we simulated two future scenarios with different land, water and biodiversity management transitions. We adopted a land systems approach, where land use and land cover are combined with data on land management, irrigation and livestock density, taking into account the characteristics of Mediterranean multifunctional landscapes, specific agricultural products, such as permanent crops, and irrigation water demands. Future land system changes were explored using the CLUMondo model for different development pathways of the region. We constrained the withdrawal of irrigation water based on existing freshwater resources. In a 'growth' scenario, we simulated a hypothetical future without consideration of environmental constraints and where food production and urban expansion are main priorities. The 'sustainability' scenario represents a future where limited water resources are extracted in a sustainable way and where areas of high biodiversity value are protected. The growth scenario projected significant intensification of land management, and loss of agro-silvo-pastoral mosaic systems. To achieve this, we calculate that the region would need to increase water withdrawal for irrigation significantly, resulting in increased pressure on freshwater resources. The sustainability scenario presents a way of increasing food production and at the same time improving the state of water resources, wetlands and traditional landscapes. Achieving this future would require improvements of yields of rain-fed systems and efficiencies of irrigated systems. The results indicate that coordinated environmental policy together with appropriate market access are needed to steer the regions land management towards a more sustainable future while ensuring food production.

1. Introduction

Most of the Earth's land surface has been changed as a result of human use, with large environmental consequences and both positive and negative impacts on human well-being (Ellis et al., 2010; Schmitz et al., 2012). With limited resources of land and water, a large societal challenge consist of meeting the increasing demand for food and living space for growing populations in the context of climate change. These challenges are especially significant for the Mediterranean, a dynamic and densely populated region with severe constraints on land and water resources (Giorgi and Lionello, 2008; Giannakopoulos et al., 2009; García-Ruiz et al., 2011; Fader et al., 2016). The Mediterranean has a long history of land use, resulting in valuable cultural landscapes created throughout centuries (Blondel et al., 2010; Tieskens et al., 2017), and is one of the most rich areas in terms of biodiversity (Cuttelod et al., 2009). On the other side, human activities in the region have resulted in significant degradation of soil and water resources (García-Ruiz et al., 2011; Karamesouti et al., 2015).

Resulting from its cultural and environmental characteristics and its long land use history, the Mediterranean Basin hosts a diversity of land systems of varying intensities and levels of (multi)functionality. Intensive systems have higher yields and produce most of the crops in the region, a large part of them being exported. These systems however also have high water demands (Daccache et al., 2014) and can negatively affect the quality of soil contributing to land degradation (Karamesouti et al., 2015). Traditional mosaic systems represent

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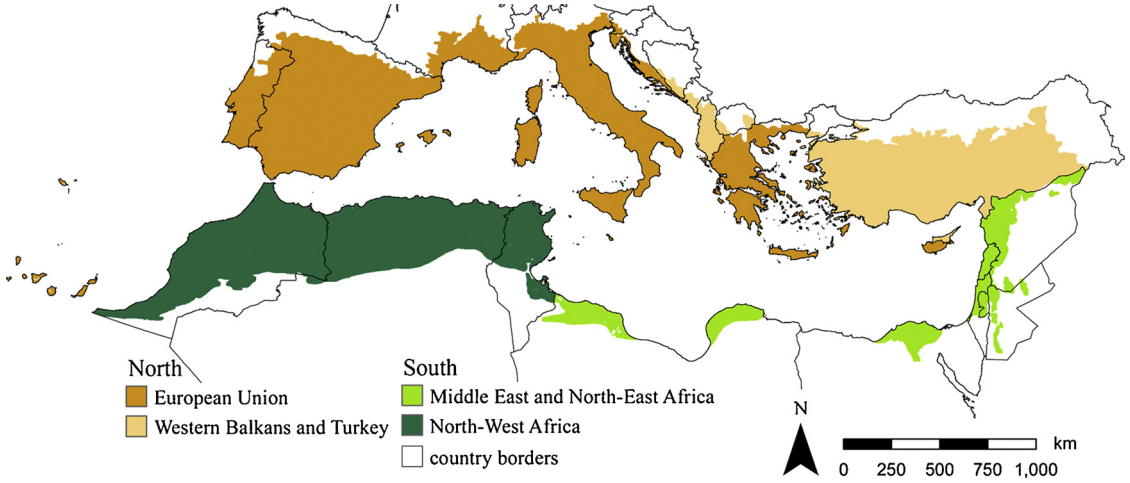

Fig. 1. The studied Mediterranean ecoregion with its 4 sub-regions.

landscapes, where human activities and environmental conditions are intricately linked. An example is the *dehesa / montado* system of Spain and Portugal, where different activities such as livestock grazing, cereal production, and forestry occur simultaneously (Joffre et al., 1999). Although these areas have lower yields, they contribute significantly to total regional food production (Blondel, 2006; McAdam et al., 2008). Many of the traditional mosaic systems are associated with high biodiversity values (Médail and Quézel, 1999). These landscapes are particularly vulnerable to global change, threatening their supply of not only food, but a number of ecosystem services (Zamora et al., 2007; Guiot and Cramer, 2016).

The Middle Eastern and North African part of the Mediterranean region is characterized with high population pressures and increasing dependence on food imports (Wright and Cafiero, 2011). Depending heavily on food imports makes the region more vulnerable to fluctuations in food supply and prices (Sowers et al., 2010). The region hosts a considerable portion of cropland with relatively low yields, meaning that future cropland expansion and intensification will play a crucial role in satisfying the demand for food (Mueller et al., 2012). This can however exacerbate soil and water degradation, and appropriate land management will be needed to reduce these consequences, or restore soil and water resources (Cerdan et al., 2010; García-Ruiz et al., 2011). Moreover, water and land grabbing are also significant issues in the region, leading to conflicts (GRAIN, 2012; Houdret, 2012). The European Mediterranean area hosts high-input intensive agricultural systems significant for regional food production and global commodity markets. However, recent socio-economic development, such as the Greek financial crisis, have influenced the steadiness of supply of agricultural products (Pfeiffer and Koutantou, 2015). Other global change effects are the abandonment of traditional livestock grazing systems due to low economic competitiveness and reduction of livestock productivity (de Rancourt et al., 2006; Bernués et al., 2011). In summary, future global change, particularly changes to climate and population, could significantly impact the potential food supply of the Mediterranean region (Evans, 2008; Sowers et al., 2010).

Published global land change scenarios suggest significant intensification of crop production and grazing, together with urban expansion in the Mediterranean region (Hurtt et al., 2011; Letourneau et al., 2012; Souty et al., 2012; van Asselen and Verburg, 2013). These global studies often do not consider specific regional characteristics that could affect these processes, such as the existence of a large share of permanent crops and traditional mosaic systems, and severe water limitations. Water limitation also affects intensification and cropland expansion, feedback loops which are currently not possible to study with land use models in which water availability is represented by a proxy, such as precipitation (NRC, 2014). Simplified proxies can only influence the spatial distribution of intensive systems and do not limit cropland expansion or intensification based on available water resources. Land use modeling studies that do take into account water scarcity are often unable to generate land use patterns with the spatial detail of most biophysical models (see for example Lotze-Campen et al., 2010).

In this study, we determine the impact of two potential future scenarios on land management in the Mediterranean region to study environmental consequences of increasing food production in the Mediterranean for the year 2050. We advance from the existing knowledge by combining global outlooks of socio-economic and climate change in a land system change model with regional spatial characteristics and configuration of land use. We are particularly interested in how global change might affect traditional Mediterranean landscapes and water resources. We also demonstrate how water resources limitations can be represented in land system models.

2. Future challenges for land management in the Mediterranean region

2.1. The Mediterranean region

We focused on the Mediterranean ecoregion defined by the approximate extent of representative Mediterranean natural communities from a biogeographical study (Olson et al., 2001). We expanded the ecoregion by also including the Nile Delta, the Po floodplain and numerous “islands” of similar ecoregions within the Mediterranean ecoregion (Fig. 1). Thematically, we divided the region into two parts, North and South, which, based on land use characteristics and biodiversity trends (Galewski et al., 2011), were subdivided into two subregions each (Fig. 1). In addition, this subdivision accounted for more uniform markets that need to fulfill their own demands for food and living space and took into account socio-economic disparities between the Northwest and South. In total, the study area covers 2.3 million km^2 in 27 countries with around 420 million inhabitants in 2015 (CAPMAS, 2015; EUROSTAT, 2016c; IIASA, 2016).

We identified four major challenging trends for the region based on various documents on the future of the Mediterranean (Appendix A): 1) increasing population and continuous urban sprawl; 2) agriculture and food production; 3) threatened biodiversity, and 4) significant climate change impacts and increasing water scarcity.

2.2. Population and urban expansion

The total population in the southern (Fig. 1) Mediterranean countries is expected to increase by 43% until 2050, and by 16% in the

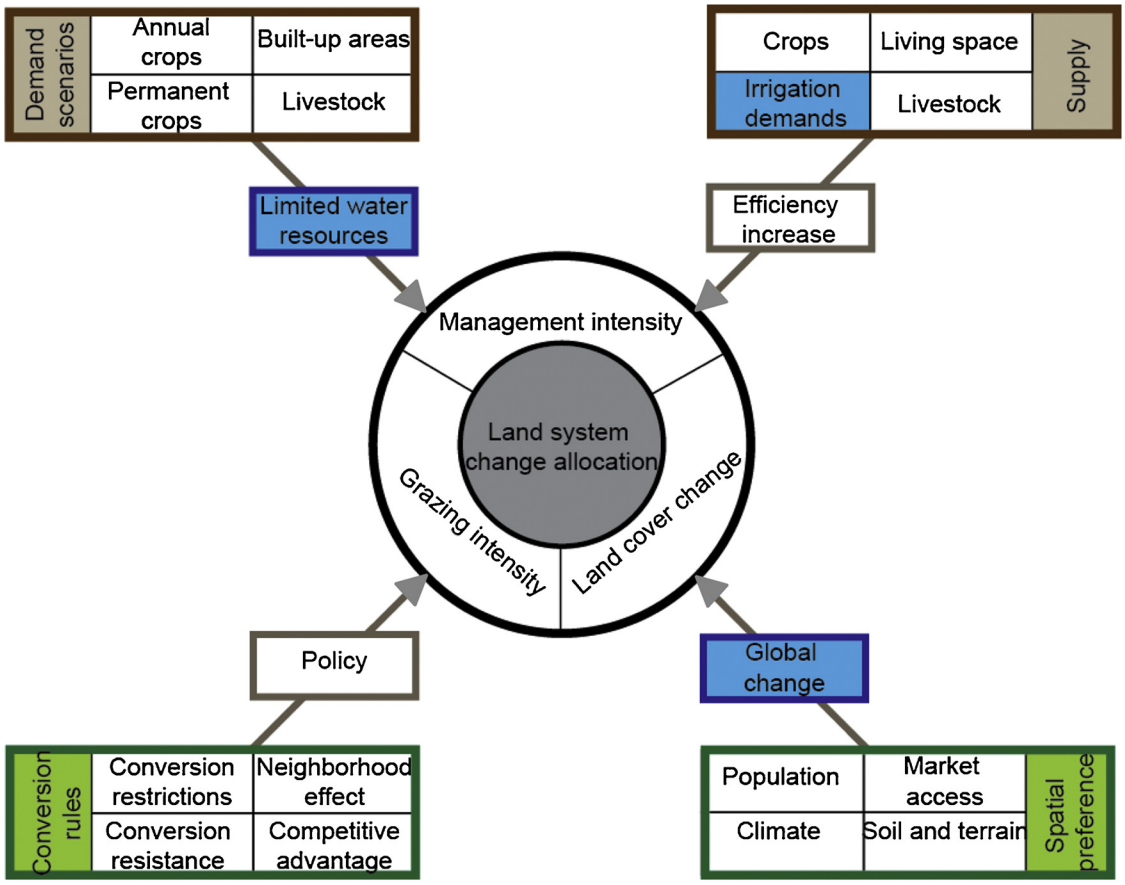

Fig. 2. CLUMondo land system change concept.

North (Fig. 1, including Western Balkans and Turkey) following the Shared Socioeconomic Pathways 2 (SSP2) scenario (Kc and Lutz, 2014; IIASA, 2016). Urban population in the South is expected to increase even more by 82% (Jiang and O'Neill, 2017). Urban expansion in the Mediterranean region is defined by dispersed and poorly managed urban sprawl (Benoit and Comeau, 2012; Salvati et al., 2012). Significant portions of Mediterranean coasts are being transformed to built-up coastal landscapes (Munoz, 2003; Parcerisas et al., 2012). Agriculture is pushed further into wetlands where surface water is available (MWO, 2012). As fertile areas in the region are limited to river plains and coastlines, a large extent of cropland is lost due to soil sealing (Mediterranean 2030 Consortium, 2011). Future population increase will undoubtedly result in further pressure on coastal urban areas, especially near existing large urban agglomerations (European Commission, 2011).

2.3. Agriculture and food production

Agriculture in the region reflects its socio-economic disparities. The northern part hosts high-input intensive agricultural systems, with most of the crops being exported. In contrast, the Southern Mediterranean hosts a considerable portion of cropland with low yields and less efficient agricultural management (Mueller et al., 2012). Trade regulations, protection of the European market and food safety requirements pose serious constraints to the Southern Mediterranean countries to export commodities such as fruit and vegetables (Larson et al., 2002; Cioffi and dell'Aquila, 2004; García Martinez and Poole, 2004). Access to agricultural technology, subsidies and loans is unequally distributed in the region and is more accessible to farmers in the north-western part. Pasture based systems are becoming less competitive, due to high labour costs – on-farm resources are being substituted with external inputs, promoting intensive livestock systems near urban areas (Steinfeld et al., 2006; Bernués et al., 2011). This has resulted in the increase in landless livestock systems in the Mediterranean region (Steinfeld et al., 2006).

2.4. Biodiversity

The Mediterranean ecoregion was identified as one of the world's biodiversity hotspots, as it hosts a large number of plant and animals species, numerous among them endemic (Cuttelod et al., 2009). The presence of these species is closely related to extensive Mediterranean landscapes, particularly agro-silvo-pastoral mosaic systems (Médail and Quézel, 1999) and wetlands (Cuttelod et al., 2009). The transformation of these systems into intensive, single function cropland systems, or their abandonment into woodland can have a significant impact on the biodiversity of the region, including changes in landscape and plant community structure (Médail and Quézel, 1999). Only 5.5% of the region's area is protected, with 90% of protected areas in the Mediterranean North (Benoit and Comeau, 2012; FAO, 2013). Among the main threats to the region's biodiversity are also urban concentration and expansion in coastal areas (FAO, 2013). Human activities have also affected Mediterranean wetlands, through increased water extraction or livestock grazing (Houérou, 1993; Ayache et al., 2009).

2.5. Climate and water constraints

The region is projected to experience warming exceeding global trends, with most climate change scenarios also resulting in reduced water availability (Chenoweth et al., 2011; Keenan et al., 2011; Guiot and Cramer, 2016). Climate change and water scarcity have even been proposed as potential contributors to conflicts in the region (e.g. Gleick,

2014; Kelley et al., 2015). Water scarcity is likely to pose severe limitations to the agricultural sector in the future, as numerous countries risk not being able to meet irrigation requirements (Fader et al., 2016). Already today, freshwater resources in the region are being extracted at unsustainable rates, not allowing for natural replenishment (FAO, 2016). However, improved irrigation efficiency and a shift to crops with lower irrigation demands could considerably lower the requirement for irrigation water withdrawal in the region (Daccache et al., 2014; Fader et al., 2016).

3. Methods

3.1. Land system change simulation

Land systems characterize human-environment interactions in landscapes and are defined as combinations of land use and land cover, livestock and management type and intensity (van Asselen and Verburg, 2012; Turner et al., 2013). The use of land systems is a particularly suitable approach for the Mediterranean region with its diverse mosaic landscapes that may not be easily disentangled into separate land cover classes. Moreover, land systems allow a clear quantification of goods and services provided by each land systems unit, necessary to simulate future change. To simulate future land system change until 2050, we applied the CLUMondo model (Fig. 2).CLUMondo simulates land system changes driven by defined demands for specific goods or services provided by land systems, taking into account the local spatial characteristics (van Asselen and Verburg, 2013). As a baseline, we used the Mediterranean land systems map for 2010 (Fig. 3, Malek and Verburg, 2017a). Each land system is characterized by an average cropland and urban extent (% of the land system unit area of 4 km2), and livestock density (livestock units in nr. per unit). In the land systems map, irrigated cropland systems are present on areas equipped with irrigation. Intensive rain-fed cropland was identified on areas where fertilizer application, field size or yields indicate intensive agriculture. The remaining rain-fed cropland was identified as extensive (for details on the method see Malek and Verburg, 2017a). Every land system provides annual and/or permanent crops, livestock and consists of a certain fraction of built-up area (Appendix B). The land systems' output of crops (annual and permanent) is a value specific to each land system. These values were calculated based on crop production statistics to land systems and are described in Appendix B.

The actual output of annual and permanent crops was based on agricultural production statistics for 2010 (EUROSTAT, 2013; 2016a, 2016b). We used subnational statistics to exclude non-Mediterranean parts of countries (France, Spain, Italy, Turkey), where a significant share of crops is produced. For countries in the Southern Mediterranean, we looked at national statistics on cropland areas and production in subnational units within the Mediterranean ecoregion. In most countries, virtually all crops were produced in the Mediterranean part (for example, 99% in Algeria and Morocco). The only exception was Egypt, where 65% of the crops are produced in the Nile delta, which we used to adjust national crop production statistics (FAO, 2016; Mohamed, 2016). Crop production was aggregated for each sub-region, and all land system output values present a mean for a specific sub-region. We used the SPAM database to identify the shares of crops produced in irrigated, intensive rain-fed and extensive rain-fed systems (You et al., 2014). Total crop production was then scaled according to these shares and calculated for the appropriate land system type (e.g. irrigated systems were associated with crops produced on irrigated cropland, intensive rain-fed with crops produced in intensive cropland). We used agricultural statistics for 2010 for two reasons. First, the year 2010 presents the most recent year where crop production statistics were consistently reported for subnational units in our study area. Secondly, the reported national crop production for 2010 deviates the least from the average national crop production of the last 20 years (less than 2%).

Annual crops consist of cereals (wheat, maize, barley and rice), and vegetables (fresh vegetables, potatoes and tomatoes). In the Mediterranean, wheat, maize and barley present the majority of cereals,

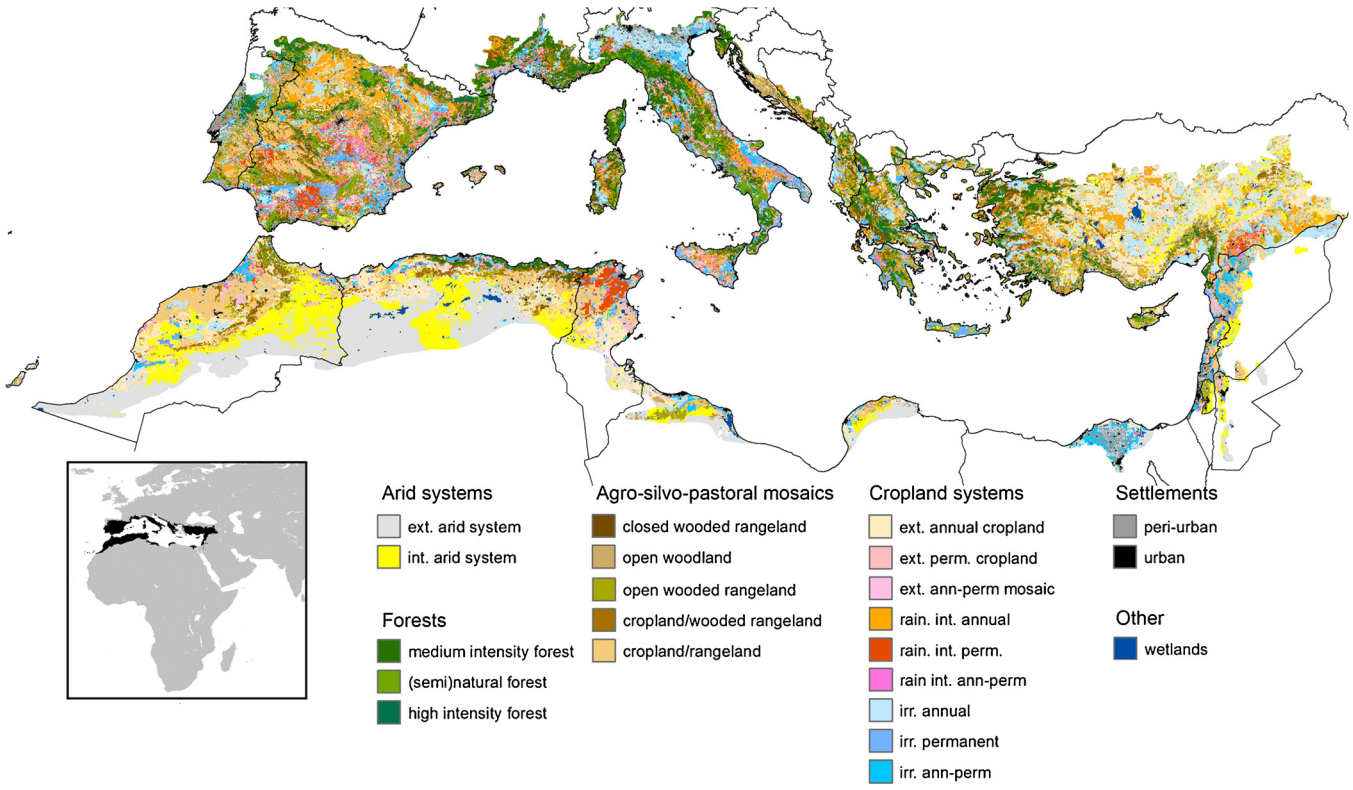

Fig. 3. Mediterranean land systems map (based on: Malek and Verburg, 2017a).

Table 1
Demands for annual and permanent crops, livestock and built-up areas for the Mediterranean region for 2010 (EUROSTAT, 2013, 2016a, 2016b), and 2050 (modified from Fricko et al., 2017; Riahi et al., 2017; Popp et al., 2017).

	2010		Growth 2050		Sustainability 2050	
Region	North	South	North	South	North	South
Annual crops (10^6 t)	138.23	78.62	163.53	110.61	153.19	101.89
Permanent crops (10^6 t)	68.40	21.73	80.88	30.56	78.33	30.12
Livestock (10^6 nr)	22.44	13.66	28.23	16.92	26.33	15.99
Built-up areas (10^3 km^2)	21.52	12.63	25.07	18.71	23.72	16.23

with rice having a significant share in Egypt and Italy (EUROSTAT, 2013, 2016a, 2016b). Permanent crops consist of fruit, olives and dates. Olives, grapes and citrus alone amount to over 20% of total crop production in the Mediterranean region (Daccache et al., 2014). Livestock output is based on the values derived from a global livestock database, with values for bovines, goats and sheep calculated to livestock units (Robinson et al., 2014).

CLUMondo allocates changes to land systems based on spatial preference, spatial restrictions and competition between land systems (van Asselen and Verburg, 2013). Spatial preference or local suitability describes the probability of each location (grid cell) to host a specific land system, based on its biophysical and socioeconomic conditions. CLUMondo allocates future land change in locations with highest preference for a defined land system. To calculate spatial preferences the relationships between the spatial occurrence of a specific land system and location factors (explanatory biophysical and socioeconomic variables presented in Appendix C) are investigated using logistic regression. This results in maps presenting the likelihood of occurrence of different land systems as a function of local environmental and socio-economic conditions (Appendix D). Spatial preference maps are updated annually to account for population and climate change, as described in later sections. Spatial restrictions are constraints for changing specific land systems, such as protected areas. Spatial restrictions can either completely constrain land change, or allow predefined changes to land systems (e.g. woodlands can change into forests in a protected area). To achieve a solution, CLUMondo iterates different land system allocation combinations until it fulfils all demands for a specific year for a specific scenario. Although the model can handle the provision of numerous crops and livestock units by land systems, it will promote the most competitive (while accounting for both the occurrence likelihood and competitiveness in terms of the services delivered towards the demand) system for that demand. The model is described in more detail by (van Asselen and Verburg, 2013) and is available (as open-source) at http://www.environmentalgeography.nl/site/data-models/data/clumondo-model/.

3.2. Limiting water resources

Besides achieving the most likely land system allocation under the defined demands, CLUMondo can take into account the limitations of the allocated land systems in terms of resource use. In this study, use of water resources was constrained, by applying a threshold on the total irrigation water withdrawal. This situation is implemented using physical limitations as a maximum level of resource use which cannot be overshot. If the demand cannot be satisfied fully with irrigated land systems under the given constraints, CLUMondo has to fulfill it with rain-fed land systems. This limits the allocation of irrigated land systems with high water requirements, although they have the highest crop output (Appendix B) and are therefore promoted by the model if irrigation is not limited. To satisfy the demand for annual and permanent crops, CLUMondo needs to consider other land systems without irrigation demands, but also with lower output for these crops, having a tradeoff on the conversion of (semi-)natural areas.

To associate irrigated land systems with irrigation water withdrawal, we used spatially explicit irrigation data on areas equipped with irrigation (Siebert et al., 2005, 2013). Irrigation demand values for irrigated land systems were based on the extent of irrigated areas, which we linked to national and subnational irrigation water withdrawal statistics (EUROSTAT, 2013, 2016a, 2016b; FAO, 2016). This resulted in mean values of irrigation water withdrawal per cell of irrigated land system for each region (Appendix B). The available water resources, that served as a limit for irrigation water withdrawal, are based on water resource statistics on the national (Mediterranean South: FAO, 2016) and subnational level (Mediterranean North: EUROSTAT, 2013, 2016a, 2016b; Egypt: FAO, 2016; Mohamed, 2016).

3.3. Scenarios

3.3.1. Scenario introduction

To study potential pathways to fulfill the growing food production and the demand for living area in the Mediterranean region, we have developed two contrasting scenarios: 'growth' and 'sustainability'. The scenarios follow different assumptions in terms of production of annual and permanent crops, and livestock, and the demand for built-up area up to 2050 (Table 1). Both scenarios are based on global SSP2 projections for the region in terms of regionally produced food, however modified to fit the storyline of each scenario as described in Table 2 and Appendix E. The production values for annual and permanent crops, and livestock are based on the SSP2 marker scenario projections for food production (Fricko et al., 2017; Riahi et al., 2017; Popp et al., 2017). These projections are a result of integrated assessment models, where the remaining consumption is satisfied with imports. In the projections, the Mediterranean North maintains producing more than it consumes in 2050, whereas the dependency of the Mediterranean South on food imports increases despite significant crop and livestock production growth (Alexandratos and Bruinsma, 2012). The Mediterranean South imported 56% of its total crop consumption in 2007 (Wright and Cafiero, 2011), which is projected to increase to 73% in 2050 (World Bank, 2009; Alexandratos and Bruinsma, 2012). The demand for built-up areas is based on the population growth rate of the SSP2 scenario (Kc and Lutz, 2014). The scenarios differ from each other significantly regarding the handling of major challenges the Mediterranean region will be facing in the future. In particular, in the sustainability scenario, freshwater is explicitly regarded as a limited resource for irrigation, while in the growth scenario, it is not. Technical details of translating the scenario storylines to the CLUMondo land system model are described in Appendix E.

3.3.2. Growth scenario – production maximization through growth

Under the growth scenario the current economic disparities between the sub-regions are assumed to remain unchanged. Each subregion follows its own goals, aiming to satisfy its own demands. Environmental issues, such as freshwater resources depletion are not considered.

Urban expansion: Urban expansion has priority to any other land process. Low density peri-urban systems are promoted, continuing urban sprawl. Rural abandonment continues in the North of the Mediterranean Basin. In the South, rural population increases until 2020, followed by a gradual decrease (Jiang and O'Neill, 2017).

Agriculture and food production: Agricultural intensification has priority – extensive areas are promoted to convert to intensive ones, achieved by higher use of fertilizers, irrigation and herbicides. Yield improvement technology remains unequally distributed in the region. Yield gaps are not closed, however achieve 75% of the attainable yield for irrigated systems. Landless livestock systems are promoted – indoor breeding systems on intensive cropland or near urban areas are subject to 15% intensification. No food waste reduction efforts are made.

Biodiversity: The extent of protected areas in the Mediterranean does

Table 2
Summary of main storyline elements of the two scenarios.

	Growth	Sustainability
Population change and urban expansion		
Population in 2050	19.5% increase in the North, 47.4% increase in the South (SSP2)	
Demand for built up areas	10% higher than annual population growth rate	30% lower than annual population growth rate
Spatial pattern	Urban sprawl allowed, urban land has priority over all other uses. No expansion in protected areas	Compact and denser urban areas promoted, no expansion in protected areas
Agriculture and food production		
Food demand	Projected SSP2 marker scenario food production	10% lower annual crops demand growth. 10% higher permanent crops growth due to easier exports. Reduction in food waste resulting in total 5% lower food demand.
Yields	Irrigated systems achieve 75% of the attainable yield	Northern Mediterranean: closed yield gap for rain-fed intensive and irrigated systems Southern Mediterranean: extensive systems reach 50%, rain-fed intensive 75% and irrigated 90% of the attainable yield.
Livestock	15% efficiency improvement to landless livestock systems	5% livestock efficiency improvement to all systems
Access to irrigation	Same as baseline, 5% lower spatial preference for areas with low market accessibility	Improved accessibility
Biodiversity		
Protected areas	Only existing PAs	17% of national priority areas designated as PAs, transformations to high-intensity land systems in such areas are not possible
Wetland management	No changes	Intensity in cropland and livestock reduced by 30%
Grazing in arid areas	No limitations	Intensification in arid areas limited
Climate change and water		
Climate change scenario	RCP 4.5	RCP 4.5
Location specific deduction to rain-fed systems	reduced spatial preference in areas with aridity index < 0.5 by 0.1	reduced spatial preference in areas with aridity index < 0.5 by 0.05
Water resources	No limitations and changes to water withdrawal	Limited water withdrawal. Withdrawal reduced by 25%
Irrigation efficiency	N.A.	35% more efficient

not increase, but existing protected areas are conserved. Cropland and livestock activities with low intensity (extensive cropland and mosaic systems) are allowed in protected areas. Wetlands continue to be used for cropland and used for intensive livestock grazing. Grazing in arid areas is uncontrolled.

Climate and water constraints: Same crops are being grown as today which, given the reduction in precipitation and increases in evaporation, results in lower suitability for rain-fed intensive systems occurring in semi-arid areas due to climate change. Water resources can be exploited without limitations.

3.3.3. Sustainability scenario – fulfilling the Mediterranean sustainable development goals

The sustainability scenario describes a future, where the future Mediterranean region is characterized by prosperity, solidarity and stability. Throughout the region, national governments and other actors agree to follow shared environmental and development goals.

Urban expansion: Urban sprawl is limited and well planned. A new type of a Mediterranean compact city emerges, denser urban areas are promoted. Rural population remains stable.

Agriculture and food production: A common Mediterranean market involving all countries around the Mediterranean sea (Fig. 1) is established. It results in a liberalization of agricultural trade, with improved access to agricultural technology, loans and subsidies for everybody. The entire region can easier satisfy its demand through additional food with imports, and can export even more commodities such as permanent crops. Yield gaps on irrigated and rain-fed intensive cropland are closed in the North, and reach 90% (irrigated) and 75% (rain-fed intensive) of attainable yield in the South. Land based livestock systems are promoted. The efficiency of livestock production systems in terms of output is improved, for example by improving breeds or fattening of herds (Bernués et al., 2011). A moderate reduction in food waste due to changed dietary habits (North) and improvement in the food supply chain (South) results in a lower increase in total regional demand for agricultural production.

Biodiversity: The entire region applied coherent and consistent environmental policies and conservation tools. The extent of protected areas in the region reaches the 17% of terrestrial ecosystems as specified by the "Aichi target" of the UN Convention for Biodiversity (http://www.cbd.int/sp/targets), being a considerable improvement for the Mediterranean South (Pouzols et al., 2014) (Appendix F). Low intensity cropland and livestock grazing (extensive cropland and mosaic systems) are allowed in newly established protected areas. Wetlands use by intensive crop production system and grazing of livestock is decreased. Grazing intensification in arid areas is limited in order to combat desertification. Ecological focus areas are assigned as 5% of area set aside in all rain-fed systems. This way, landscape elements with higher biodiversity values are being protected or established.

Climate and water constraints: Due to improvement in cultivars and crop changes (for example with crops with lower water demands), intensive rain-fed areas can expand more than they do in the growth scenario (Daccache et al., 2014). Improvements in irrigation infrastructure and changes to irrigation type (e.g. drip irrigation lead to a 35% improvement in irrigation efficiency. Irrigation water withdrawal is limited to 75% of current total withdrawal, to allow more water for biodiversity and ecosystems.

3.4. Climate and population change

In both scenarios, global change was included either through a change in the location factors which underpin the spatial preference map for land system transitions, or as a land system change constraint. We used results from downscaled global climate models from CMIP5 (Hijmans et al., 2005; Taylor et al., 2012) forced by the RCP4.5 greenhouse gas radiative forcing representative concentration pathway. RCP4.5 is a cost-minimizing mitigation scenario, presenting a "median" and probable pathway compared to other scenarios (Thomson et al., 2011). We calculated the mean of 19 CMIP5 simulation outputs (Appendix G) for both temperature and precipitation for the years 2041–2060, referred to as year 2050. Based on these projections, we generated annual temperature and precipitation maps, which were then used to derive annual potential evapotranspiration (PET) and aridity index (AI) maps (Trabucco et al., 2008; Zomer et al., 2008) (Appendix H). Temperature, precipitation and PET served as location factors in the

logistic regression, and AI was used to limit particular processes (Appendix E). For example, forest expansion was possible only in areas with AI > 0.65 (Zomer et al., 2008).

To account for population change, we updated the 2010 population density map using the SSP2 projection growth rates (CIESIN, 2015; Jiang and O'Neill, 2017). We used urban population growth rates for areas with higher population density (> 250 inhabitants/km^2) for both scenarios (Appendix I). This corresponds well with population change projections for the Mediterranean region (Benoit and Comeau, 2012). Changes to rural population were applied to the rural population density map (Appendix C), and were also based on global SSP2 projections (CIESIN et al., 2011; Jiang and O'Neill, 2017).

3.5. Changes to productivity of land systems

Changes to productivity were implemented by changing the output of each land system in time (Appendix B). We first studied the current average yield gap of land systems using yield gap data for major crops (Foley et al., 2011). Then, we calculated annual growth rates of land system output changes to achieve crop yields assumed attainable under the scenario conditions (Tables 2 and 3). The attainable yields were based on plausible improvements to nutrient management and irrigation as proposed by Mueller et al. (2012). Mueller et al. (2012) did not consider climate change impacts on crop yields, although the potential to close yield gaps in different regions was constrained by climate conditions.

Because the used productivity changes do not explicitly account for climate change impacts on productivity, we compared the annual productivity increases in both scenarios (Table 3), with other scenario studies that focus on future yield change in the Mediterranean region. Our assumed productivity increases are lower than in other studies, except in both climate change studies (Parry et al., 2004; Giannakopoulos et al., 2009). In these two studies, technological improvements and adaptation were however limited or not considered. In contrast to the studies mentioned in Table 3, we assumed cropland productivity will only increase in intensive rain-fed and irrigated systems, and not overall in the cropland sector. We did not improve the productivity of existing extensive cropland or traditional multifunctional mosaic systems. Moreover, we did not consider potential increases to water demands of different crops. Studies have demonstrated that improving the irrigation efficiency can help maintaining cropland productivity and allow for expansion of irrigated areas in the Mediterranean (Fader et al., 2016; Malek and Verburg, 2017b; Saadi et al., 2015).

4. Results

4.1. Changes to management of Mediterranean land systems

In both scenarios, extensive cropland systems decreased most (Table 4). This is either through intensification of management, or due to abandonment and subsequent conversion to woodlands. There is also a drastic increase in urban systems in the Middle Eastern region, particularly Syria, Israel, Palestine and Jordan. The largest expansions of irrigated areas can be observed in Turkey, Tunisia and Morocco. The inclusion of water limitation for crop irrigation in the sustainability scenario impacts the way in which the demands for food are satisfied in comparison to the growth scenario (Fig. 4). In some parts of North-West Africa and Turkey, limited freshwater availability for irrigation results in more rain-fed intensive areas compared to the growth scenario (Fig. 5). In Algeria, the Western Balkans and Turkey, limited water availability does not necessarily result in more rain-fed intensive area, as a significant part of food demands is fulfilled by intensifying mosaics, higher efficiency improvement, while simultaneously the overall food demand is lower due to a decrease in food waste. Land system results for both scenarios are depicted in Fig. 4, with more detailed land system conversions shown in Table 4, Fig. 5 and 6, Appendix J and downloadable in GIS format from www.environmentalgeography.nl. Fig. 7 presents the two future scenarios in three focus areas, the Iberian peninsula, Middle East and Turkey, and in Tunisia.

4.2. Changes to traditional Mediterranean landscapes

More mosaic systems are preserved in the sustainability scenario: 60% more compared to the growth scenario. Whereas a significant share of mosaic systems remain the same, still around 58% and 32% of mosaics change in the growth and sustainability scenario respectively. Around 36% of mosaics in the growth and 21% in the sustainability scenario were changed to other mosaic systems (Table 5). Based on the level of multifunctionality, the mosaics either changed to another mosaic with the same level, or to a mosaic with a higher level. The level of multifunctionality was identified based on the number of activities defining the system. A change from a mosaic land system with 2 activities (e.g. woodland-rangeland mosaic) to another mosaic with 2 activities (woodland-cropland mosaic) was identified as a change in management on a same level of multifunctionality. The extent of mosaics, that change from another type of mosaic while keeping the same level of multifunctionality is significant in both scenarios (Table 5). Such processes were projected in southern Spain, Portugal, Western Balkans and south-western Turkey (Fig. 6). An interesting process is the increase in functionality, occurring in both scenarios. This process represents additional activities on existing land systems, such as introducing livestock to woodlands or woodland-cropland mosaics. The model transformed land systems with lower output in terms of crops and livestock such as woodlands, to land systems with higher output occurring in similar locations (similar spatial preference) such as woodland-cropland or woodland-rangeland mosaics. These processes are projected to occur on extensive areas in Algeria, Western Balkans and western Syria (Fig. 6). Differences in the extent of losses of Mediterranean agro-silvo-pastoral mosaic systems between the two scenarios are mostly a consequence of cropland expansion and intensification – more than twice as many mosaics are transformed to intensive or irrigated cropland in the growth scenario compared to the sustainability scenario (Table 5). In some areas, agro-silvo-pastoral mosaic systems expand. This is mostly caused by an increase in livestock density in extensive cropland systems, or through the introduction of livestock to cropland that was abandoned during the simulated time period. Increases in livestock density and grazing on abandoned cropland were projected mostly in NW Africa, but also in southern Spain (Fig. 6 and 7).

4.3. Water resources

As the use of water resources was constrained only in the sustainability scenario, the overall lower water extraction values are considerably lower than in the growth scenario. Clearly, the constraints on water use have influenced the model's choice of land systems. In the growth scenario, all regions demonstrate a significant increase of irrigation water withdrawal (Table 6). The highest expansions of irrigated cropland systems and consequent increases in irrigation water withdrawal are projected in the sub-regions Western Balkans and Turkey and NW Africa. We used the pressure on freshwater resources index (PFR), to describe the water stress of the sub-regions in the two scenarios (Table 6). It is defined as the share of total irrigation water withdrawal in available freshwater resources (FAO, 2016). There are considerable differences between the regions in the baseline year (FAO, 2016) (Table 6). Both sub-regions of the Northern Mediterranean have a PFR index that is below 20%, which still enables biological functioning of freshwater bodies and does not result in water stress as a limiting development factor (Arnell, 1999). This is mostly due to the more abundant freshwater resources in these regions and a lower dependence of their agriculture on irrigation (Appendix B). The Middle East and NE Africa sub-region already has unsustainable freshwater

Table 3
Future changes to cropland productivity (in % per year), together with considered climate change effects and future technological improvements in this study and comparable studies. EU: European Union, WBTU: Western Balkans and Turkey, MENA: Middle East and North Africa, NWA: Northwest Africa.

	EU	WBTU	MENA	NWA	Climate change	Technological improvements
Observed yields change (1961-2000)	1.92	0.34	2.49			
International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009)						
High estimate	1.33	1.33	1.75		Crop responses to temperature and precipitation change, water stress (relatively small climate impacts in 2050)	Depend on investments in agricultural science and technology, and water productivity
Low estimate	0.71	0.71	0.79			
Millenium Ecosystem Assessment (MEA, 2005)						
High estimate	0.87	0.75	1.05		Crop responses to temperature and precipitation change, water stress	Increased fertilization and irrigation efficiency, major investments in agricultural research, GMOs, high mechanization level
Low estimate	0.35	0.42	0.63			Insufficient investments in irrigation and cropland productivity, difficulties to maintain fertility of land
Agrimonde (Ronzon, 2014)						
High estimate	0.81	2.22	0.67		Water stress, slower yield increase, increased variability of precipitation	Rapid technological improvements enable to overcome the impacts of climate change
Low estimate	0	1.33	0.24			Rural development and ecological intensification to increase cropland productivity, irrigation techniques, water preservation
Parry et al. (2004)						
High emissions	−0.59 to +0.04	0.08	−0.08		Crop responses to temperature and precipitation under current agricultural management	Limited: changes in planting dates, additional fertilization and irrigation on existing cropland
Low emissions	−0.17 to +0.17	0.04	−0.04			
Giannakopoulos et al. (2009)	−0.01 to +0.11	0.11 to 0.29	−0.27 to -0.13	−0.1	Crop responses to temperature and precipitation, and seasonality	No improvements. If adaptation is implemented, cropland productivity can stay the same or increase with changing sowing dates and cycles and irrigation.
This study						
Sustainability – irrigated / int. rain-fed	0.11 / 0.05	0.33 / 0.16	0.56 / 0.43	0.94 / 0.43	Productivity of rain-fed cropland is limited by current climate (Mueller et al., 2012), future climate limits the spatial extent of rain-fed cropland	Investments both in rain-fed and irrigated systems, resulting in moderate productivity increase
Growth – irrigated / int. rain-fed	0 / 0	0.16 / 0	0.45 / 0	0.78 / 0.26		Investments focus on high output systems (irrigated only), low productivity increase

Table 4
Changes to spatial extent of Mediterranean land systems in %.

Land system		Growth	Sustainability
Forest systems	medium intensity forest	−6.0	−12.4
	(semi)natural forest	24.8	22.0
	high intensity forest	−79.9	−43.1
Arid grazing systems	extensive arid system	−71.9	−18.2
	intensive arid system	84.1	16.6
Agro-silvo-pastoral mosaics	closed wooded rangeland	24.4	23.7
	open woodland	−92.1	−61.6
	open wooded rangeland	57.8	78.0
	cropland/wooded rangeland	−11.5	−34.9
	cropland/rangeland	29.0	63.1
Extensive rain-fed cropland	extensive annual	−82.9	−64.1
	extensive permanent	32.3	−53.3
	extensive mosaic	−70.8	−64.3
Intensive rain-fed cropland	rain-fed intensive annual	8.2	15.4
	rain-fed intensive permanent	41.6	−14.7
	rain-fed intensive mosaic	44.5	44.1
Irrigated cropland	irrigated annual	79.1	12.6
	irrigated permanent	26.0	38.5
	irrigated mosaic	−49.3	31.2
Settlements	peri-urban	10.2	2.1
	urban	72.2	44.7

extraction rates, as some countries (e.g. Egypt and Libya) are already extracting more resources compared to their renewable water resources (Table 6).

5. Discussion

5.1. Future changes of Mediterranean land systems

Modelling the future of land use and management intensity is a central part in integrated assessment models (Wise et al., 2009; Stehfest et al., 2014). However, given the global character of these assessments, and the strongly simplified land cover representations, little insight into the potential changes in the specific Mediterranean land systems is acquired from these studies. While single case studies have documented the (potential) response to global change in the Mediterranean (Bugalho et al., 2011; Keenan et al., 2011; Nainggolan et al., 2012; Parcerisas et al., 2012), no earlier study specifically focused on the impacts of global change across the entire region and took into account the impacts of the limited water availability. Land systems provide highly appreciated benefits for the regional population: the region is a significant producer of highly demanded commodities, such as olives and grapes, and the region hosts vast areas of traditional multi-functional mosaic landscapes, that are well studied (Blondel, 2006; Daccache et al., 2014). The region is projected to witness significant climate changes, mostly in the form of temperature increases, decreases of precipitation and more frequent climate extremes. At the same time, demographic changes and fast urbanization will pose additional

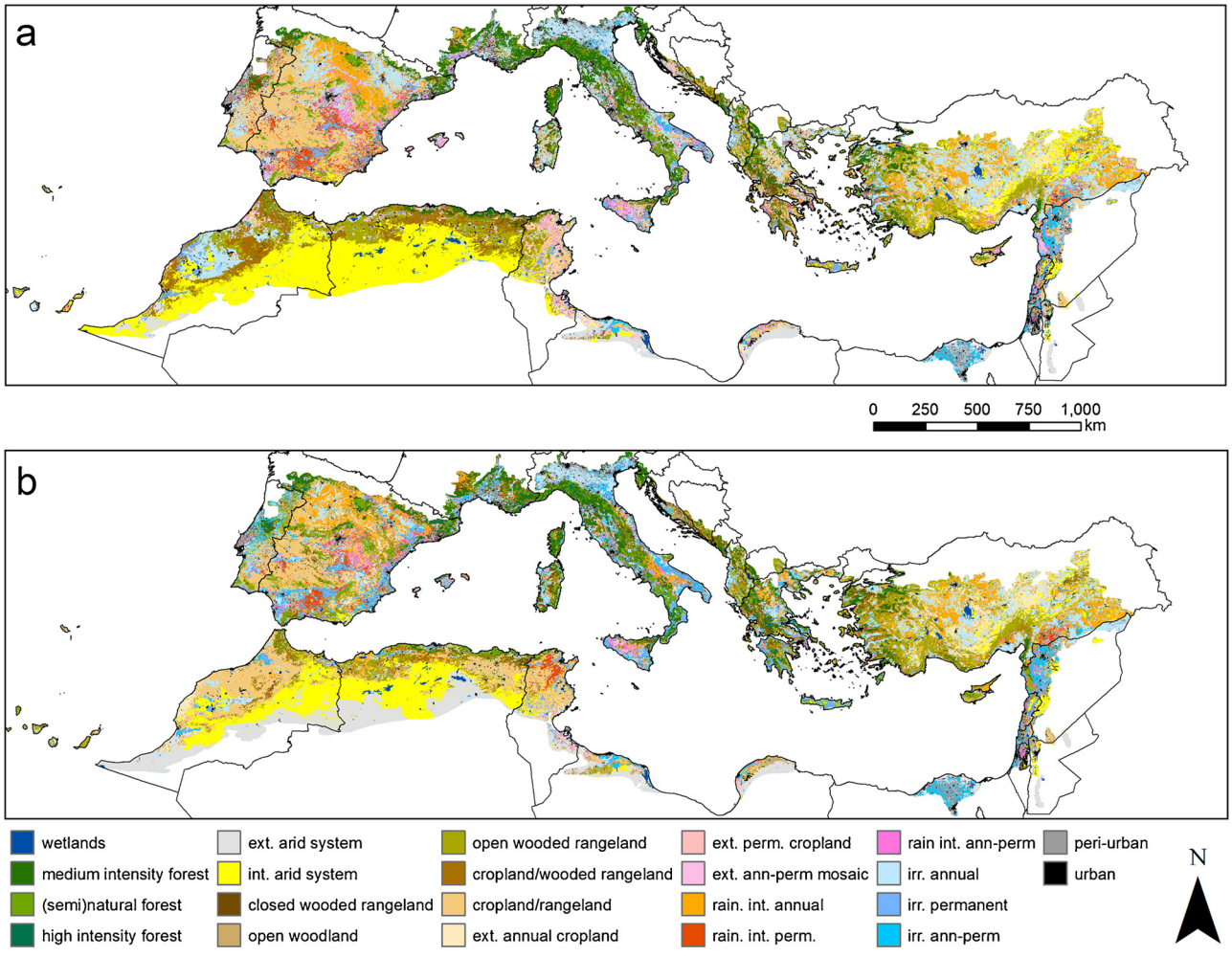

Fig. 4. Future land systems in 2050 as simulated for the two scenarios: (a) growth, (b) sustainability. High resolution version of the map is available in Appendix J.

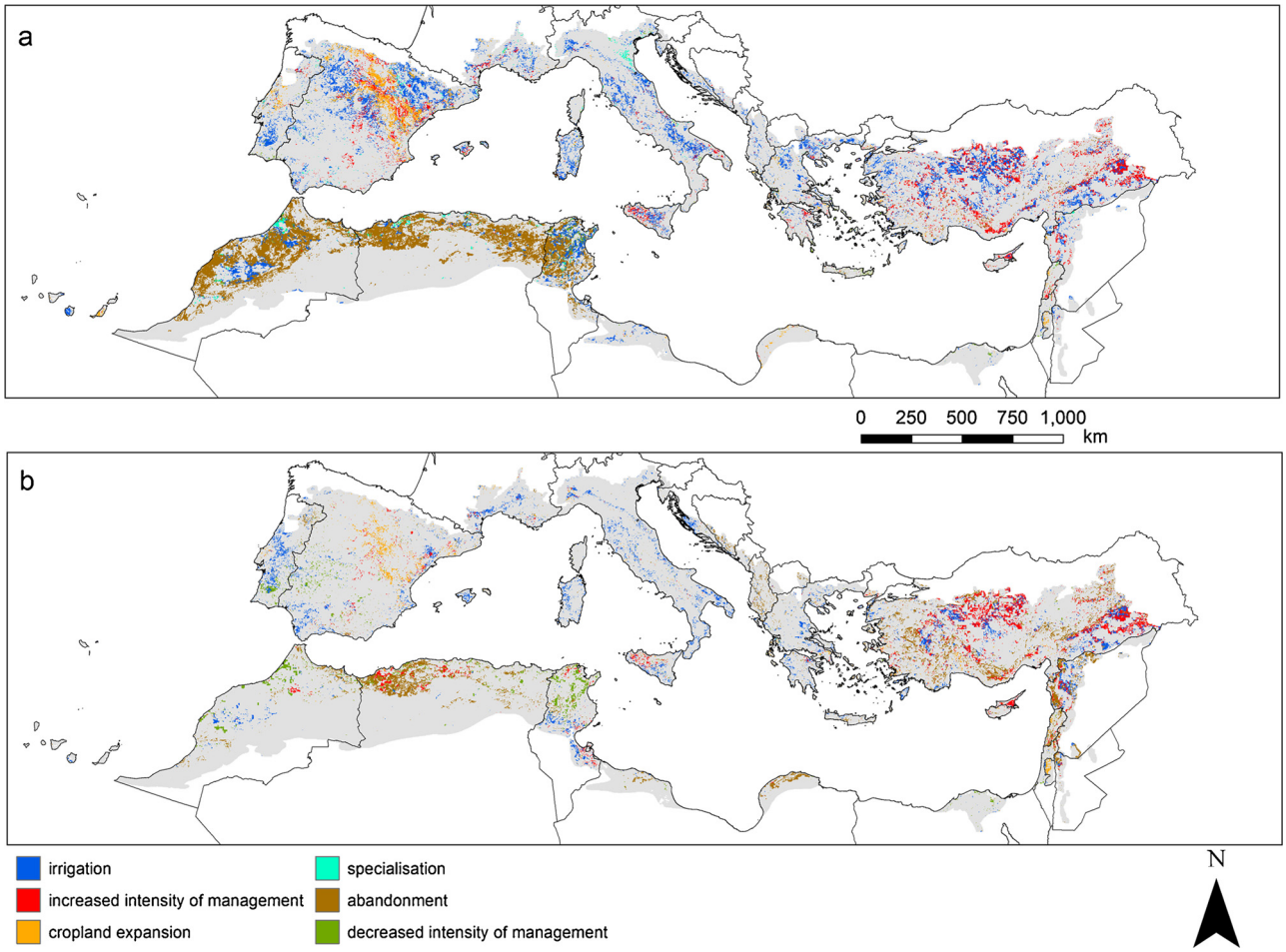

Fig. 5. Changes in land management intensity in the (a) growth and (b) sustainability scenario. High resolution version of the map is available in Appendix J.

challenges to land systems.

The two fundamentally different scenarios we developed, demonstrate two potential pathways of how land systems may respond to a growing population in the Mediterranean. While the future of land management of the region is more likely to be between these two scenarios, the scenarios sketch how differences in the level of technological development and the implementation of policies concerning rural development, water management and biodiversity lead to strongly different land system outcomes. Both scenarios represent a future, where the southern Mediterranean countries continue to depend on food imports for a significant part of their food demand and are based on global integrated assessment calculations of trade, demand and supply between regions. In all global level scenarios it is acknowledged that to feed the growing population of the region, significant food imports will still be needed (Wright and Cafiero, 2011). Our results indicate that already under those conditions enormous changes in land systems are needed to meet such demands for production in the region. Moreover, when looking at the changes between the two scenarios, we can identify adaptation opportunities in land management to avoid changes to mosaic land systems and cropland expansion (Fig. 8). Significantly more areas are subject to irrigation, intensification and changes to mosaics in the growth scenario compared to the sustainability scenario, suggesting the potential outcomes of successfully following common sustainable development goals. Technological improvements and nutrient management, improved irrigation efficiency, and protection of traditional land use systems were thus recognized as successful measures to increase the resilience of traditional Mediterranean landscapes. Nevertheless, the sustainability scenario also projected changes to intensity and irrigation differently from the growth scenario. These locations mostly present the tradeoffs of expanding the protected areas network (Fig. 8).

Despite a lower demand for agricultural products in the sustainability scenario, more land system transformations to intensive rain-fed cropland were projected for some areas, notably in NW Africa. In this region rain-fed intensive areas provide much less output compared to other regions and are characterized by high yield gaps (Mueller et al., 2012). The lower use of irrigated cropland to meet agricultural demands therefore comes at the cost of a larger expansion of rain-fed croplands in this scenario. The intensification of rain-fed cropland was mostly projected in areas that will maintain more favorable climatic conditions in the future, such as northeast Spain. Other locations of intensifying rain-fed cropland (e.g. north of the Atlas mountains) correspond well with other research (van Asselen and Verburg, 2012; Mueller et al., 2012).

The model projected significant increases in irrigated cropland in both scenarios, because irrigated systems in most sub-regions have the highest output of crops, and were thus promoted by the model to fulfill agricultural demands. Equipping rain-fed cropland with irrigation, particularly in semi-arid regions as the Mediterranean, is among the most implemented adaptation options to reduce risks to climate change (Smit and Skinner, 2002). Due to projected climate change, the extent of areas most suitable for rain-fed intensive cropland systems decreased. A major limiting factor for rain-fed agriculture is high aridity, and arid and hyper-arid areas are projected to expand in the NW Africa sub-region (Appendix H). Although necessary improvements in irrigation efficiency to maintain current water withdrawal with projected expansion of irrigated areas are possible (Fader et al., 2016), the two southern Mediterranean sub-regions already today have unsustainable

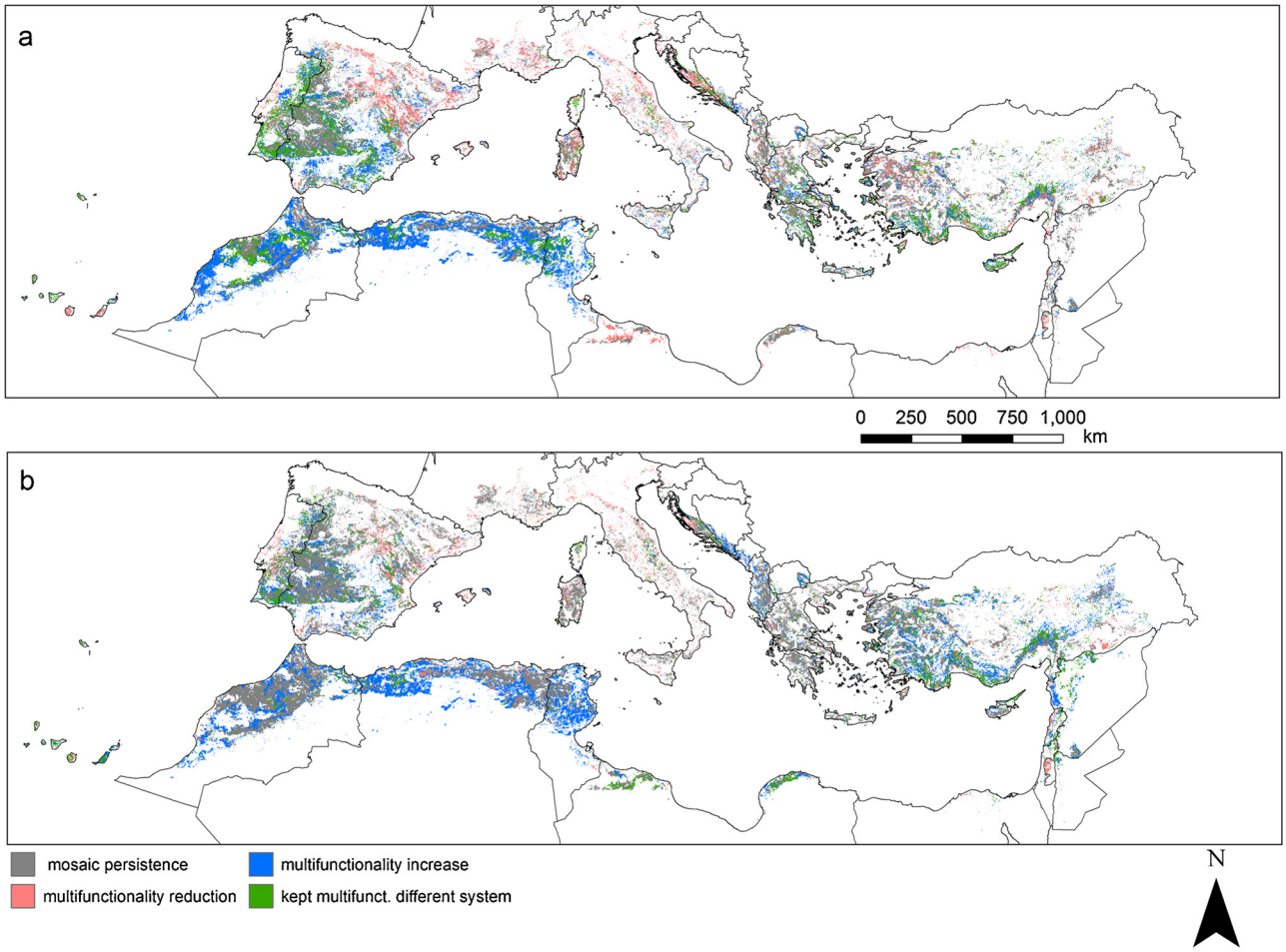

Fig. 6. Land system change affecting mosaic land systems in the growth (a) and sustainability (b) scenario. High resolution version of the map is available in Appendix J.

water withdrawal levels. Furthermore, the growth scenario does not consider projected decreases in water resources as may be expected due to depletion of aquifers and climate change (Vörösmarty et al., 2010; Chenoweth et al., 2011). Despite the efforts on finding new water resources, water reuse and desalination, the growth scenario is strongly overestimating the water availability.

The drastic expansion of irrigated areas projected in the sub-regions Western Balkans and Turkey, and NW Africa is expected under the 'growth' scenario. Particularly in NW Africa, irrigation is needed in order to increase the yields, as studies suggest that only improving nutrient management and mechanization will not be enough to improve cropland productivity in this area due to local climatic conditions (Mueller et al., 2012). Generally, the sustainability scenario resulted in less intensive rain-fed and irrigated cropland (Fig. 8), which can also be attributed to a 5% lower demand due to a decrease in food waste. Nevertheless, our reduction in demand for agricultural products is conservative, as studies suggest higher potentials to reduce agricultural demands in case of drastic improvements in the supply chain or diet change (Parfitt et al., 2010; Garrone et al., 2014).

Expansion of multifunctional systems, projected by the model in both scenarios can be explained two-fold. First, these areas are subject to expansion of protected areas in the sustainability scenario, which prevents more intensive land systems to be established, but allows for the conversions into other (more) traditional extensive systems. Secondly, climatic and soil characteristics of these areas constrain rain-fed intensive agriculture. Similar transitions have already been observed at the local scale in areas such as south-eastern Spain, as a result of environmental conditions, policies favoring woodland expansion and less profitable rain-fed agriculture (Nainggolan et al., 2012). This increase of multifunctional areas can be defined as sustainable intensification, where satisfying future demands for crops and livestock occurs simultaneously with meeting sustainability objectives (e.g. biodiversity protection and strengthening rural communities) (Garnett et al., 2013). Multifunctional land systems have been acknowledged as a significant adaptation option to climate change, particularly for smallholder farmers (Verchot et al., 2007). Although multifunctional areas contribute less to satisfying food demand as compared to intensive cropland, they can also be recognized as an effort to rehabilitate and conserve land and water resources. Such increased land productivity (in terms of crop and livestock production) with simultaneous sustainable land use follows the objectives of the United Nations Convention to Combat Desertification (UNCCD, 1994).

This study took into account competing demands for food production and living space. Traditional Mediterranean land systems are, however, providing other significant ecosystem services, such as non-timber forest products like mushrooms or cork, fire prevention, carbon storage, soil erosion prevention and landscape aesthetics (Bugalho et al., 2011; Almagro et al., 2013; Guerra et al., 2016). These services could also act as additional demands especially if covered by environmental, rural development and tourism policies (Eitelberg et al., 2016). Future studies should therefore study the effects of maintaining different benefits provided by traditional Mediterranean mosaic systems besides food. This way, the extent of mosaic systems needed to provide a certain extent of important ecosystem services can be determined, as well as potential tradeoffs in irrigation and intensification in other areas.

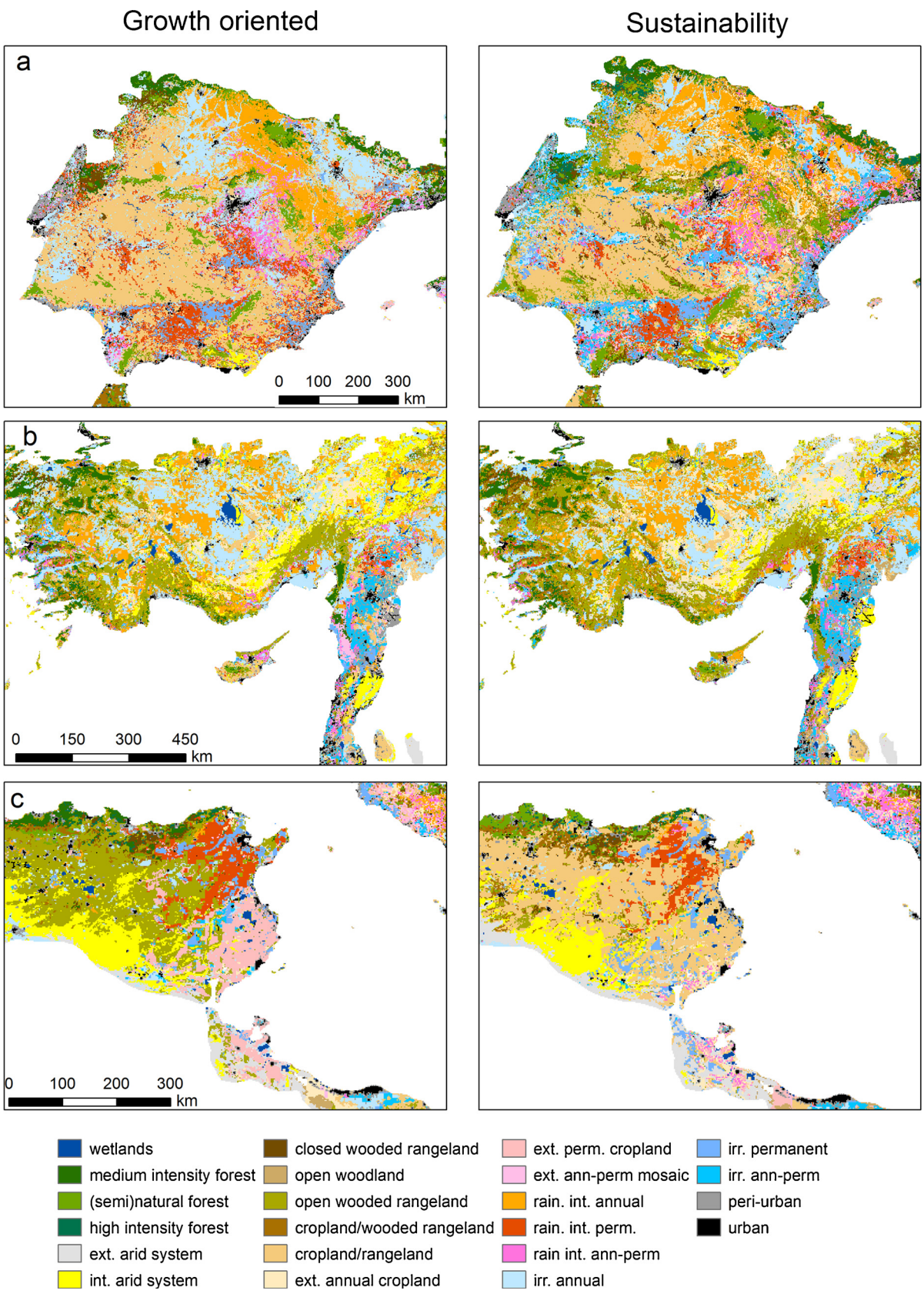

Fig. 7. Future 2050 land systems scenarios in focus areas, (a) Spain and Portugal, (b) Middle East and Turkey, (c) Tunisia.

Table 5
Changes to agro-silvo-pastoral mosaic system until 2050.

Change process (%)	Growth	Sustainability
Persistent multifunctional systems	42.43	67.98
Multifunctionality loss towards monoculture	21.57	10.66
Similar level of multifunctionality, different management system	23.48	15.13
Increase of functionality within mosaic systems	12.52	5.86
Extensive cropland transformed to multifunctional systems	44.87	53.40

Table 6
Irrigation water withdrawals and pressure on freshwater resources (PFR) in the Mediterranean in 2010 and 2050. Irrigation water withdrawals and freshwater resources and are based on national and subnational statistics (EUROSTAT, 2013, 2016a, 2016b; FAO, 2016).

	Sub-regions W. Balkans and Turkey	EU	Middle East and NE Africa	NW Africa
Changes in irrigation water withdrawal compared to baseline levels (%)				
2050 – growth	+55.9	+37.0	+21.4	+59.9
2050 – sustainability	−18.0	−21.5	−27.9	−33.6
PFR (%)				
2010	11.8	10.2	94.4	30.2
2050 – growth	18.4	13.9	114.7	49.6
2050 – sustainability	9.7	8.0	68.1	20.0
Irrigation efficiency improvement to maintain current water extraction in growth scenario (%)	35.8	27.0	17.6	37.4

5.2. Water limitation as a contribution to land change modelling

Significant improvements in the modelling of future land use have been made in the recent decades, including more precise coverage of spatial, temporal and thematic resolution and moving beyond an approach based only on dominant land cover (Hurtt et al., 2011; Letourneau et al., 2012; Souty et al., 2012; Bryan et al., 2016). Land management which used to be represented in a simplified manner as a class of regional management factor (Bouwman et al., 2006; Bondeau et al., 2007), can now be described using different management intensity metrics, such as livestock numbers, fertilizer inputs or yield gaps (Souty et al., 2012; van Asselen and Verburg, 2013). This is necessary, as often socio-economic changes are not limited to direct land cover changes, but predominantly lead to changes in management intensity or irrigation. In this study, we managed to quantify the relative changes required for both land management and land cover to fulfill future food demands. Our results show that for the growth and sustainability scenario respectively 61% and 51% of the increase of agricultural demand is met by new irrigation, 23% and 36% by cropland intensification and only 12% each by cropland expansion. Our study therefore confirms that the inclusion of changes in land management (irrigation and intensification) may be more important than land cover changes in modeling of future scenarios. This way we contribute to better understanding of land system processes leading to increased pressure on land and water resources, and consequent land degradation (UNCCD, 1994).

The growth scenario presented a continuation of worldwide trends, where the demands for food and living space are fulfilled by increasing more productive, monofunctional, land systems at the expense of traditional systems, as is also suggested by global scale studies (van Asselen and Verburg, 2013; Eitelberg et al., 2016). In this scenario, the likelihood of spatial variables and location preferences for where irrigated systems were considered in the allocation of land systems by the model. However, the expansion of irrigated agriculture was not limited by water availability. Consequently, the growth scenario resulted in more than twice as much irrigation water withdrawal in the sub-regions NW Africa and Western Balkans and Turkey. An assumption of unlimited water availability can therefore lead to an overestimation of expanding irrigated areas. Such increases of water extraction are unlikely to happen in the Mediterranean basin, partly because of the regional expected impacts of climate change (Elliott et al., 2014). On the other side, not constraining water availability is a useful scenario exercise as it demonstrates the land systems distribution that might otherwise be possible (Fig. 8). Our results show the necessity of including the reality of limited water availability when simulating future changes to land systems, particularly in (semi)arid regions. Many global studies disregard this issue and suggest significant cropland expansion and intensification in other semi-arid areas (van Asselen and Verburg, 2013; Eitelberg et al., 2016), which undoubtedly will have an impact on future water resources. The approach presented in this paper can, therefore, be applied in areas that face similar resource constraints, and improve the understanding of how future cropland expansion and intensification are responding to situations of water stress.

In this study we used spatially explicit irrigation data, linked to irrigation water withdrawal and freshwater resources statistics. This resulted in mean values per cell of irrigated land system, not considering areas where water withdrawal values can be considerably higher due to higher potential evapotranspiration. Incorporating water cycle processes is needed to improve the availability and constraints of water resources. One example could be to use spatially explicit data on water availability and water extraction, if such data was available on a more detailed resolution (Brauman et al., 2016). A higher resolution of water withdrawal of land systems might be achieved, by operating on a catchment scale. Nevertheless, data on crop production is not available on the same scale, which would result in a mismatch of management levels - water management on catchment scale vs. agricultural management on a regional or national scale. Moreover, using spatially explicit water withdrawal data would mean additional uncertainties to our approach, related to the models used to derive such data. Using regional or national scale irrigation withdrawal data furthermore ensures a higher transferability of our approach to similar (semi)arid areas with increasing food demand and high water stress (e.g. other areas in the Middle East, south Asia, China, North America…). Another challenge would be to consider groundwater reserves, as these are often non-renewable, or their exploitation exceeds groundwater recharge rates. Although there is data on irrigation from groundwater resources, for the Southern Mediterranean it is based on national statistics (Siebert et al., 2010), which makes it difficult to limit their spatial extent and occurrence. Irrigation using groundwater might also occur in the hyper-arid (desert) part in the Middle East and North Africa, outside our study area (Mediterranean ecoregion).

We only focused on water withdrawals for agriculture and did not account for the competing demands for municipal and industrial water use. Whereas in the European Union irrigation amounted for around 40% of total water withdrawals, it is the main source of water withdrawals in other sub-regions (Appendix K). Future socio-economic development particularly in the southern Mediterranean will however also likely result in increased demands for non-agricultural water use (Flörke et al., 2013). Livestock water use was also not considered, mostly as the statistics in all sub-regions except the European Union equal irrigation with agricultural water withdrawals (FAO, 2016). Nevertheless, livestock also has significant water demands influencing freshwater resources (Mekonnen and Hoekstra, 2012). Further research on improving the data on water use and how different sector compete for water resources is therefore needed.

5.3. Storyline to modeling translation and uncertainties

In this study, we present a transparent and clear methodology on translating storylines to modeling, as demonstrated by detailed

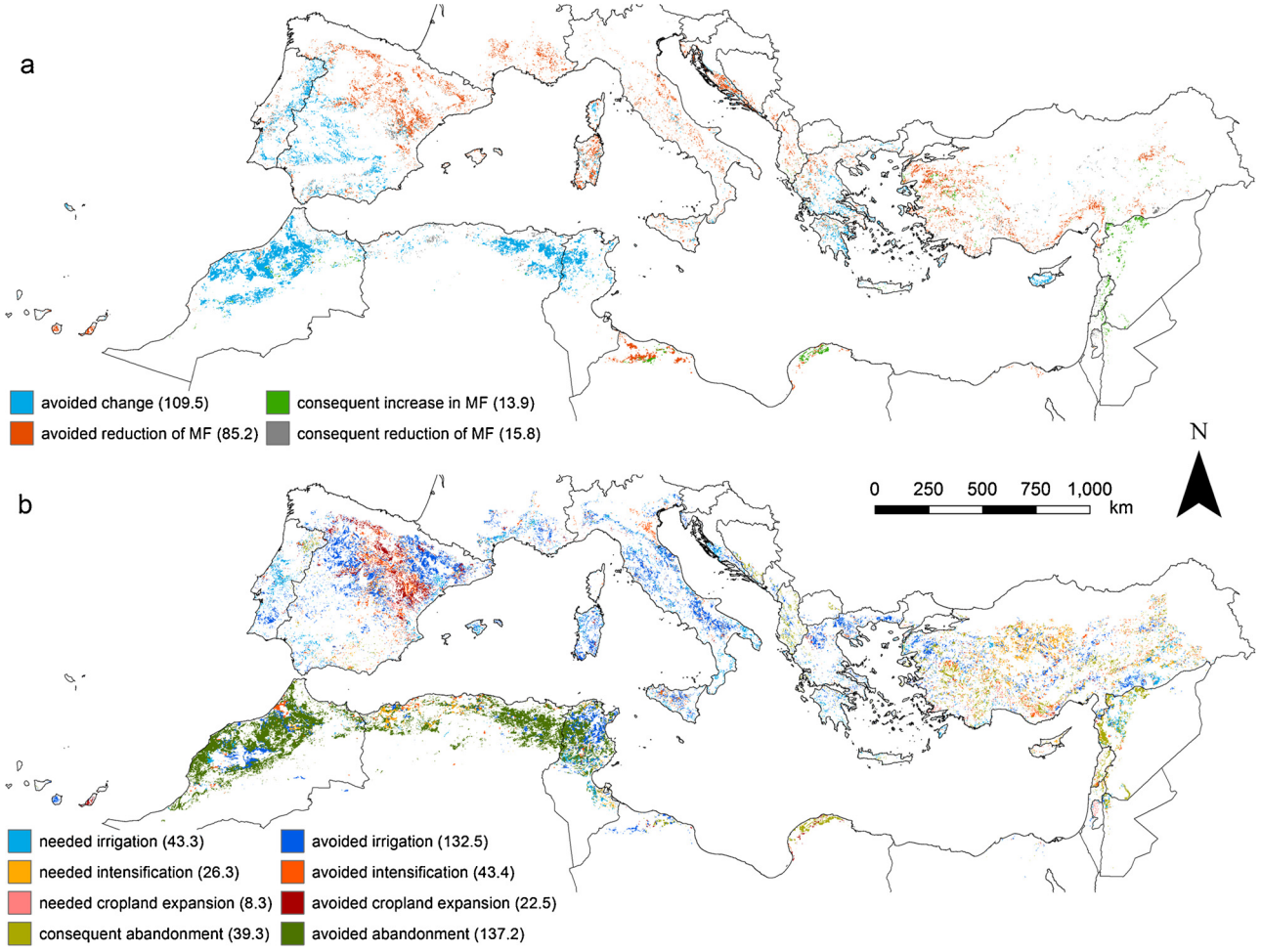

Fig. 8. Future land management opportunities for the Mediterranean region, defined as spatially explicit changes between the two scenarios, with the sustainability scenario as a reference. The two maps present the consequences of implementing the policies of the sustainability scenario, described as avoided and consequent changes to a) mosaic land systems and b) irrigation, intensification, cropland expansion and abandonment. Values in brackets are in 1000 km^2.

supplement information. Individual steps of our study are presented, ranging from preparing dynamic input files for changing temperature and precipitation, to defining model parameters reflecting the storyline. This way, we aimed at improving the presentation of the translation of specific policy assumptions to model parameters.

In analyzing global change effects on local scale land management, we went beyond applying global demand projections only. We developed two storylines that describe regional challenges on a higher detail – global SSP storylines are more broad and general (Riahi et al., 2017). For example, in our study water management is one of the most crucial challenges for the Mediterranean, influencing the development of scenarios significantly.

Model studies are sensitive to uncertainties and errors in the input data. We aimed to reduce the uncertainties in our approach by relying mostly on crop production and irrigation water withdrawal statistics. Nevertheless, combining numerous spatial data can result in an aggregation of uncertainties. For example, our baseline land systems map is heavily dependent on inputs such as land cover, with the southern Mediterranean having higher observed inaccuracies compared to the northern part (Malek and Verburg, 2017a). Moreover, in this study we focused on the Mediterranean ecoregion. Irrigated systems in deserts, such as oasis like date plantations in North Africa, are also contributing to total crop production and also irrigation water withdrawals.

One of the biggest uncertainties for land system modelling are assumptions on improvements in technology and efficiency. Agreement in efficiency improvements used in different models is usually higher in developed regions, such as the European Union (Paillard et al., 2014), whereas we observed relatively large variations in other regions, such as the whole Southern Mediterranean and Turkey. This could be linked to the fact that yield gaps are larger in developing countries than in developed countries (Ramankutty et al., 2008; Mueller et al., 2012). Yield improvement scenarios are often optimistic, not considering the expected impacts of climate change (Long, 2006). Our yield improvements were rather conservative, considering the region's socio-economic and environmental characteristics (Mueller et al., 2012). We did not apply efficiency improvements to all land systems as it is the case in some similar studies (van Asselen and Verburg, 2013; Eitelberg et al., 2016). For example, in NW Africa, improvements in nutrient management are needed to achieve higher yields. Improved nutrient management on extensive cropland could however also mean a transition to a more intensive cropland, resulting in higher yields. Finally, we did not consider potential new crop production systems in the future. One example of such system are greenhouses with significantly higher agricultural output. Such systems could occur on a wider spatial extent, as they are less dependent on local environmental characteristics. Assumptions on technological improvement, particularly increases of yield are significantly influencing the extent of simulated cropland expansion, intensification and new irrigation and need to be considered carefully. To reduce the uncertainties related to future cropland productivity, future research should focus on differences between projected yields or cropland efficiency.

6. Conclusions: what are the consequences of global change for the Mediterranean?

In this article, we assessed how global change might influence future land systems in the Mediterranean. Similarly to global scale studies, we projected significant increases in intensively managed and irrigated cropland for the Mediterranean basin. Our study shows, that to a certain extent, it is possible to preserve traditional Mediterranean mosaic systems. The growth scenario depicts a future, where more mosaic systems will be abandoned or transformed to more intensive systems. Rural development policies focusing on improving the socio-economic conditions of rural areas, and increasing yields within traditional mosaic systems, as shown in the sustainability scenario, can be an alternative to further cropland expansion or conversion to monoculture intensive cropland systems. We have also shown, that an expansion of protected areas in the region is possible without compromising the region's abilities to produce food. The same goes for reducing the intensity of cropland and grazing activities in wetlands.

The two scenarios represent different pathways on managing Mediterranean freshwater resources and dealing with water shortages. In the growth scenario, water resources are continued to being depleted at unsustainable rates in the future with significant investments into alternative water resources. Some of them are already taking place today: water reuse, desalination, large infrastructural projects such as dams or channels (Hochstrat et al., 2010; Pedrero et al., 2010; El Gammal and Ali, 2011). Improving the state of freshwater resources, as projected by the sustainability scenario, is possible by increasing the efficiency of rain-fed cropland and strengthening the role of multi-functional mosaic systems.

Our results indicate, that increased food production in the Mediterranean can be accompanied by preserving landscapes with higher cultural and biodiversity values, and decreasing the pressure on freshwater resources. However, we also show that such a future is only possible under the implementation of common Mediterranean sustainable development goals and orchestrated agricultural and environmental management strategies.

Acknowledgements

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.gloenvcha.2018.04.007.

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